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TABLE OF CONTENTS AND EXTRACTS FROM "GAS-TURBINE AIRCRAFT ENGINES"

The following information comprises a table of contents and extracts from Aviatsionnyye Gazoturbinnyye Dvigateli, by N. V. Inozemtsev and V. S. Zuyev, published by State Publishers for the Defense Industry. The parts translated are indicated below. Ten figures are appended.

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FOREWORD

This work represents the first attempt to systematize the theory and design of the gas-turbine engines used in aviation.

The authors consider it necessary to give methods for determining the thrust of jet engines and to familiarize the reader with the general characteristics of various types of jet engines as prerequisites to the theory and design of aircraft gas-turbine engines.

A special chapter in the book is devoted to thermodynamic computations for gas-turbine engines; these computations permit thermodynamic calculation of the gas flow through the engine and determination of the main parameters and characteristics of the engine.

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Attention is also given to problems of fuel combustion in chambers. Several types of combustion chambers of gas-turbine engines are described and the present theory of combustion in chambers is analyzed briefly.

A large part of the book is devoted to characteristics of gas-turbine engines, determination of optimum parameters, and calculation of altitude and speed characteristics because there is not enough information on these problems at present.

Problems connected with regulation of gas-turbine engines are considered in a separate chapter. In conclusion, constructions of several present-day engines are surveyed briefly.

In writing the book, the authors used available technical literature and, to a considerable degree, data based on their personal studies. The book has been approved by the Ministry of Higher Education as a textbook for aviation institutes.

The authors wish to thank Professor Doctor M. M. Maslennikov, who read the manuscript and made valuable suggestions.

ACCEPTED TERMINOLOGY AND ABBREVIATIONS

No	Accepted Term	Accepted Abbr
1.	Jet engine	RD
2.	Jet engine operating in air	VRD
3.	Rocket engine	--
4.	Solid fuel rocket engine	RDT
5.	Liquid fuel rocket engine	ZhRD
6.	Ram-jet engine	PVRD
7.	Compressor jet engine operating in air	--
8.	Compound engine	--
9.	Gas-turbine engine	--
10.	Turbojet engine	TRD
11.	Double-channel turbojet engine	DTRD
12.	Turboprop engine	TVD
13.	Thrust	R
14.	Specific thrust (kg-sec/kg air)	R_{spec}
15.	Flight speed	v (m/sec)
16.	Thrust power	N_T
17.	Specific weight of engine (kg/kg-thrust)	g_{EW}
18.	Specific load on engine (kg/sq m)	R_F

No	Accepted Term	Accepted Abbr
19.	Specific fuel consumption (kg/kg-thrust-hr)	C_{spec}
20.	Specific fuel consumption with respect to thrust power	C_T
21.	Specific impulse (kg sec/kg of fuel)	R_i
22.	Velocity of gases flowing from the nozzle	w_5
23.	Air discharge per second	G_A
24.	Fuel consumption per second	G_F
25.	Gas discharge per second	G_G
26.	Relative fuel consumption	g_F
27.	Discharge of air through outer (external) channel of DTRD and TVD	G_{ext}
28.	Heat liberated in combustion chamber	Q_{ch}
29.	Pressure and temperature of the free air	P_o, T_o
30.	Pressure, temperature, and velocity of air in front of compressor	p_1, T_1, w_1
31.	Pressure, temperature, and velocity of air behind the compressor	p_2, T_2, w_2
32.	Pressure, temperature, and velocity of gases in front of turbine	p_3, T_3, w_3
33.	Pressure, temperature, and velocity of gases behind turbine of TRD	p_4, T_4, w_4
34.	Pressure, temperature, and velocity of gases when leaving the jet of TRD	p_5, T_5, w_5
35.	Pressure, temperature, and velocity of air in front of outer channel compressor of DTRD	p'_1, T'_1, w'_1
36.	Pressure, temperature, and velocity of air behind outer channel compressor of DTRD	p'_2, T'_2, w'_2
37.	Pressure, temperature, and velocity of gases when leaving outer channel nozzle of DTRD	p'_5, T'_5, w'_5
38.	Pressure, temperature, and velocity of gases behind the turbine driving the outer channel compressor in a DTRD and the propeller in a TVD	p'_4, T'_4, w'_4
39.	Pressure ratio of compressor according to static and stagnation pressures	π_c π_c^*

No.	Accepted Term	Accepted Abbr
40.	Pressure ratio of the diffuser according to static and stagnation pressures	π_D π_D^*
41.	Mach number	M
42.	Degree of expansion of gases in turbine according to static and stagnation pressures	δ^* δ
43.	Free energy of gases	L_{fr}
44.	Available energy of gases	L_{av}
45.	Adiabatic and actual work done by compressor	L_{ad} L_k
46.	Pressure coefficient in diffuser according to static and stagnation pressures	σ_{DIF} σ_{DIF}^*
47.	Adiabatic efficiency of compressor according to static and stagnation pressures	η_{AD} η_{AD}^*
48.	Pressure coefficient in combustion chamber (c.c.) according to static and stagnation pressures	$\sigma_{c.c.}$ $\sigma_{c.c.}^*$
49.	Turbine efficiency according to stagnation parameters	η_u^*
50.	Nozzle coefficient	ϕ
51.	Coefficient of distribution of free energy	n
52.	Coefficient of heat liberation (coefficient of completeness of combustion	$\xi_{c.c.}$

Note: Parameters of delayed flow are designated by an asterisk.

22. COMPARATIVE EVALUATION OF GAS-TURBINE ENGINES ACCORDING TO SPECIFIC PARAMETERS

The preceding calculations of characteristics of various types of gas-turbine engines permit us to make a comparative evaluation of gas-turbine engines according to specific thrust and specific fuel consumption and to make several conclusions of practical importance for determining the future aspects of development.

As can be shown graphically (Figure 243), the turboprop engine is most efficient with respect to specific thrust up to Mach numbers of approximately 1 (for $\pi_0 = 4$ and $T_3 = 1{,}200^\circ K$) and for $\eta_B = 0.8$, since it develops maximum thrust in this velocity range. The turbojet engine develops less thrust in the velocity interval M = 0-1.0, but develops greater specific thrust than the turboprop engine only for $M > 1.0$. The double-channel turbojet engine develops considerably less thrust than the turbojet or turboprop engines for Mach number from 0 to 1.5.

Graphs (Figure 244) show that the turboprop engine also has the best indexes with respect to specific fuel expenditure C_{sp} for Mach numbers from 0 to 1.0 (for $\pi_0 = 4$ and $T_3 = 1{,}200^\circ K$). The simple turbojet engine has the highest specific

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fuel consumption under these conditions. For Mach numbers from 0 to 0.9, the double-channel turbojet engine is more economical than the simple turbojet engine and less economical than the turboprop engine.

With an increase in speed, the turboprop engine compares less favorably with the simple turbojet engine with respect to specific thrust and specific fuel consumption. At $M \approx 1.0$ the turboprop engine is no better than the turbojet engine with respect to specific thrust and specific fuel consumption; and for $M > 1.0$ the latter is better than the turboprop engine in both indexes.

The advantages of the turboprop engine are increased with temperature increase in the gases in front of the turbine (T_3).

Thus the advantages (as shown in Figures 243 and 244) of the turboprop engine are retained up to high flight speeds with an increase in T_3. For example, with $T_3 = 1,600°K$ the turbojet engine compares with the turboprop only at $M = 1.2$ (for the most efficient gas velocity, the turbojet compares with the turboprop engine at $M \approx 1.5$). In the turboprop engine, the specific fuel consumption decreases and the specific thrust increases with the temperature increase of the gases in front of the turbine, i.e., the engine becomes most effective and most economical. In the turbojet engine, both the specific thrust and the specific fuel consumption increase with the increase of T_3, i.e., the engine becomes more effective but less economical.

Comparison of the double-channel turbojet engine with the turboprop for $T_3 = 1,200°K$ shows that the double-channel engine is not so efficient as the turboprop with respect to specific thrust and specific fuel expenditure for Mach numbers from 0 to 1.3. The double-channel engine has less specific thrust, but also less specific fuel consumption, than the simple turbojet engine (for Mach numbers from 0 to 0.9).

Specific parameters of various gas-turbine engines are conveniently shown as functions of Mach numbers for various altitudes. (See Figures 245 and 246, where such graphs were constructed for 11,000-m altitudes and the same values of π_0 and T_3 that were used in Figures 243 and 244.)

Graphs show that at 11,000 m, the comparative qualities of various gas-turbine engines with respect to specific parameters remain the same as at the ground. However, the advantages of the turboprop engine as compared with the simple turbojet are retained for higher speeds at this altitude than at the ground, which is explained by the decrease in flight efficiency $\eta_f = \frac{N_t}{N_e}$ of the turbojet engine with height.

Thus, at 11,000 m, R_{sp} and C_{sp} of the turbojet engine become equal to the corresponding quantities for the turboprop engine at $M = 1.4$, while at the ground these parameters become equal at $M = 1.0$.

As on the ground, the advantages of the turboprop engine are retained up to higher flight speeds with a temperature increase of the gases in front of the turbine. For $T_3 = 1,600°K$, the turboprop engine is more efficient than the turbojet engine up to $M \approx 1.70$.

The conclusions drawn for the double-channel turbojet engine for ground conditions hold for 11,000 m. However, at 11,000 m, the double-channel engine is more efficient than the turbojet with respect to C_{sp} up to $M \approx 1.2$.

Other graphs (Figures 247-250) can be drawn to show the variations of the specific parameters of various gas-turbine engines on the ground and at high altitudes (11,000 m) for $T_3 = 1,200°K$, but higher pressure of the ratios ($\pi_0 = 8$). In such graphs, the variations of the specific parameters of the turboprop and turbojet engines for $T_3 = 1,600°K$ are also shown, by dotted lines.

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Such graphs show that doubling the pressure ratio of the compressor (from $\pi_0 = 4$ to $\pi_0 = 8$) for the same gas temperature in front of the turbine ($T_3 = 1,200^{\circ}K$) increases the specific thrusts and decreases the specific fuel consumption for all gas-turbine engines (especially on the ground).

The relative position of the dependencies of the specific parameters on the flight speed in the different gas-turbine engines remains the same as for $\pi_0 = 4$. Thus, for $T_3 = 1,200^{\circ}K$ and $\pi_0 = 8$, the turbojet engine does not differ from the turboprop with respect to specific thrusts and specific fuel expenditures at the ground for $M \approx 1.0$, and at 11,000 m for $M = 1.4$; for $T_3 = 1,600^{\circ}K$, the corresponding figures are $M = 1.2$ and $M = 1.7$, i.e., the same values of M as for $\pi_0 = 4$.

The double-channel turbojet engine, as at $\pi_0 = 4$, is more economical than the simple turbojet engine on the ground for Mach numbers from 0 to 0.9 and at 11,000 m up to $M \approx 1.2$.

We should mention that the results obtained in comparing the different gas-turbine engines, with respect to specific thrust and specific fuel consumption, hold for turboprop engines only if the efficiency of the propeller remains constant for all the Mach numbers considered. If the propeller efficiency remains constant only up to flight speeds of 800-850 km per hr ($v \approx 220$m per sec, $M = 0.65$-0.7) and drops sharply beyond this point, the advantages of the turboprop engine will be retained only up to Mach numbers of 0.65 to 0.7. With a sharp drop of propeller efficiency for $M > 0.65$-0.7, the turboprop engine will have low specific thrust and high specific fuel consumption and will drop behind both the simple turbojet engine and the double-channel engine with respect to specific parameters.

Thus, a comparison of gas-turbine engines using contemporary aircraft propellers, which retain constant efficiency up to flight speeds of 800 to 850 km per hr produces the following results for the turboprop engine:

The turboprop engine is most efficient with respect to specific thrust and specific fuel expenditure for Mach numbers from 0 to 0.7. For $M > 0.7$, the turboprop engine loses its advantages due to the reduced propeller efficiency and is surpassed by both the simple turbojet engine and the double-channel engine. For $M \approx 0$-0.9 on the ground and up to $M \approx 1.2$ at 11,000 m, the double-channel turbojet engine has lower specific fuel consumption, i.e., is more economical, than the simple turbojet engine. However, the former develops less specific thrust and is less effective with respect to thrust than the simple turbojet engine. For $M > 0.9$ at the ground and $M > 1.2$ at 11,000 m, the simple turbojet engine is more efficient than the double-channel engine with respect to both specific thrust and specific fuel expenditure.

The above conclusions hold if the TRD and DTRD are not boosted by afterburning (fuel combustion behind the turbine of the turbojet engine or behind the second-channel compressor of the double-channel turbojet engine).

32. TURBOPROP ENGINES [Conclusion]

Limiting ourselves to a short survey of various gas-turbine engine designs cited above, we introduce in conclusion some average data characterizing the development of gas-turbine aircraft engines.

In 1943, gas-turbine engines had a take-off thrust varying from R = 800 to R = 1,000 kg and a specific weight g_{EW} (ratio of engine weight to thrust) of 0.7-0.8 kg per kg-thrust. By 1946-47, the thrust of gas-turbine engines had increased to R = 2,000-2 300 kg, while the specific weight had decreased to 0.3-0.5 kg per kg-thrust.

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The specific fuel consumption of turbojet engines is still high and varies from 1.0 to 1.1 kg per kg-thrust-hr. In double-channel turbojet engines, the specific fuel consumption drops to 0.65 kg per kg-thrust-hr, but its specific weight is higher (g_{EW} = 0.5-0.55 kg per kg-thrust) than present-day simple turbojet engines.

We should point out that two types of gas-turbine engines, the turbojet and the turboprop, are being developed most rapidly. Double-channel engines are being developed slowly for the present, which may be explained by the intermediate position of their characteristics (if we do not consider supersonic speeds and fuel combustion in the second channel) with respect to the characteristics of turbojet and turboprop engines.

Of interest are graphs that show specific weights of turbojet engines versus production years (Figure 375) and specific fuel consumption (Figure 376). Thus, specific fuel consumption is shown in such graphs as being maintained at C_{gp} = 1.0 kg per kg-thrust-hr level for most turbojet engines, while specific weights of engines are seen to decrease slowly but steadily (Figure 375).

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/Appended figures follow:/

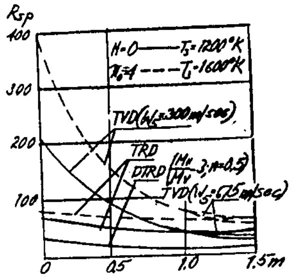

Figure 243. Specific Thrust of TRD, TVD, and DTRD Versus Mach Number for H = 0, π_o = 4, T_3 = 1,200 and 1,600° K

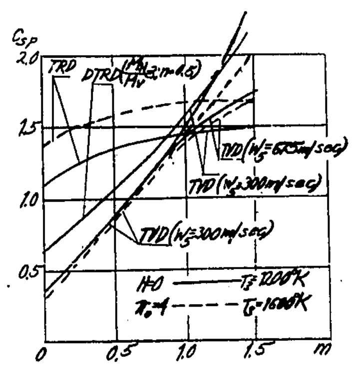

Figure 244. Specific Fuel Expenditure of TRD, TVD, and DTRD Versus Mach Number for H = 0, π_o = 4, T_3 = 1,200 and 1,600° K

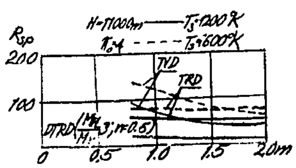

Figure 245. Specific Thrust of Turbojet, Turboprop, and Double Channel Turbojet Engines Versus Mach Number for H = 11,000 m, π_o = 4, T = 1,200 and 1,600° K

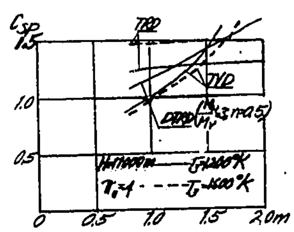

Figure 246. Specific Fuel Expenditure of Turbojet, Turboprop, and Double Channel Turbojet Engines Versus Mach Number for H = 11,000 m, π_o = 4, and T_3 = 1,200 and 1,600° K

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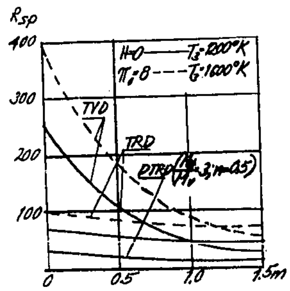

Figure 247. Specific thrust of turbo-jet. Turboprop, and double-channel turbojet engine versus Mach Number for H = 0, π_0 = 8, T_3 = 1,200 and 1,600°K.

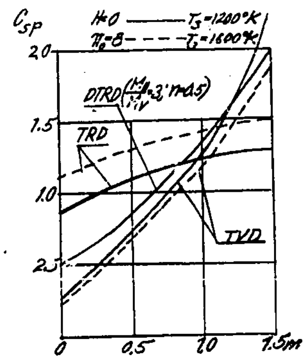

Figure 248. Specific fuel expenditure of turbojet, turboprop, and double-channel turbojet engine versus Mach Number for H = 0, π_0 = 8, T_3 = 1,200 and 1,600°K.

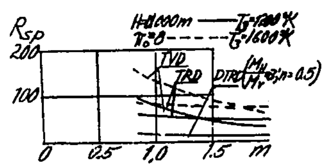

Figure 249. Specific thrust of turbo-jet, turboprop, and double-channel turbojet engines versus Mach Number for H = 11,000 m, π_0 = 8, T_3 = 1,200 and 1,600°K.

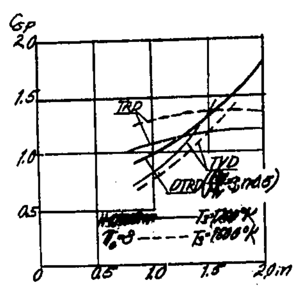

Figure 250. Specific fuel expenditure of turbojet, turboprop, and double-channel turbojet engines versus Mach Number for H = 11,000 m, π_0 = 8, T_3 = 1,200 and 1,600°K.

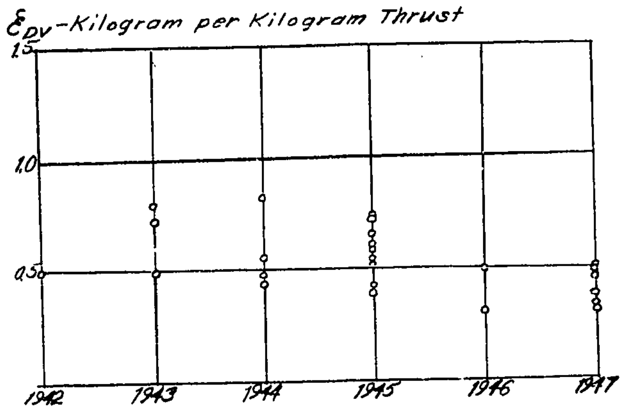

Figure 375. Diagram of specific weights of turbojet engines by production years.

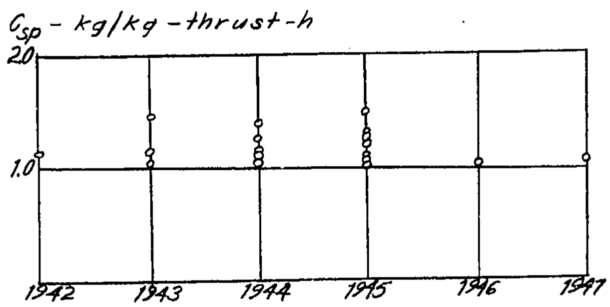

Figure 376. Diagram of specific fuel expenditures of turbojet engines by production years.

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